WHY DO WE NEED SAMPLES FROM THE MOON'S SOUTH POLE-AITKEN BASIN AND WHAT WOULD WE DO WITH THEM? B. L. Jolliff[1], C. K. Shearer[2], D. A. Papanastassiou[3], Y. Liu[3], and the MoonRise Science Team. [1]Department of Earth & Planetary Sciences, Campus Box 1169, Washington University in St. Louis, One Brookings Dr., St. Louis, MO 63130; [2]University of New Mexico, Albuquerque, NM; [3]Jet Propulsion Laboratory and California Institute of Technology, Pasadena, CA. (bjolliff@wustl.edu)

Introduction: The Moon holds an unparalleled and readily accessible record of early Solar System impact bombardment, and the South Pole-Aitken (SPA) basin on the Moon's southern farside is a key scientific target because it is the largest and oldest well-preserved impact structure on the Moon. As such, its age and the ages of subsequent large impacts within SPA have the potential to provide a new understanding of early Solar System events relating to impact bombardment during the first ~500 million years following accretion of the planets. Analysis of samples from SPA, primarily chemical and mineralogical analyses and age determinations, will answer fundamental questions about the evolution of the early Solar System including firm constraints on models for migration of giant planet orbits during the early epoch of Solar System history [1,2]. The samples will answer significant questions about the early evolution of the Moon and, by analogy, the terrestrial planets. The science associated with this mission concept is among the highest priority science for Solar System exploration as laid out by the National Academy Planetary Science Decadal Survey [3].

Samples from SPA will provide a test of the "cataclysm" or late-heavy bombardment that is implied by the analysis of lunar samples [4]. The SPA impact event was enormous, forming a basin some 2200×2500 km in size [5] and excavating materials from great depth, potentially including both crust and mantle. Its effects on the Moon were global, forming a Moon-wide stratigraphic event, and determining the age of formation will bracket the ages of other ancient, Pre-Nectarian basins on the Moon as well the origin of the apparent episode of igneous activity around 4.35 Ga [6-9]. Materials from SPA basin hold a record of the process of very large impact-basin formation and will serve as ground truth for remote sensing of SPA basin materials [10]. Volcanic rocks that occur in the SPA interior will contribute to our understanding of basin materials and chronology, and mantle heterogeneity. Paleomagnetic analyses will provide the oldest constraints on the lunar core dynamo, aiding our understanding of the Moon's earliest thermal evolution.

Chronology: Unravelling the impact chronology recorded by complex impact-melt rocks and breccias requires analysis of samples in the best terrestrial laboratory conditions and by modern, highly precise analytical methods. Coordinated petrographic and chronologic studies are required to understand age data and to distinguish, for example, crystallization and impact ages. Multiple chronometers provide data on systems with different closure and diffusion properties. The impact that produced the SPA basin melted an enormous volume of rock and reset the age of a large part of the Moon. The thousands of returned rocklets will define the age of the SPA melt and potentially of a distribution of younger ages from the later large impacts within SPA. Such age determinations will clarify whether the mechanisms proposed to account for the observed lunar cataclysm from Apollo samples are compatible with the farside SPA samples. These samples will provide a record of the duration and timing of basin impacts on the Moon as well as a key absolute calibration point for the pre-4.0 Ga chronology [11,12].

The impact cataclysm hypothesis was first indicated by clustering of ages and the identification of large-scale mobilization of Pb at ~3.9 Ga [4]. The 3.9 Ga age was also identified in Ar-Ar chronology [13]. The hypothesis was further supported by ~3.9 Ga Rb-Sr ages of melt rocks [14]. The Sm-Nd system is also now an essential analytical method for lunar chronology because it is least disturbed by later impact events [e.g., 15]. This system is important because SPA is old and has undergone later impacts that might have disturbed other systems. Because of this differential response of the chronometers to impact heating and metamorphism, samples from the SPA basin must be analyzed by all these techniques. High precision methods (TIMS: Rb-Sr, Sm-Nd, U-Pb; ICPMS: Lu-Hf; and Ar-Ar) will be made on bulk and carefully separated materials, and in-situ analyses such as secondary ion mass spectrometry (SIMS) will be conducted on mineral grains including zircon [e.g., 16], other Zr- and U-rich minerals, and phosphates [17].

Impact Basin Formation Processes: Sophisticated numerical modeling of the SPA impact event has been the object of recent studies [e.g., 18]. These models may be further constrained with sample data. The age of SPA formation will constrain the thermal state of the Moon's lithosphere at the time of the impact. Samples will reveal the rock types and compositions of impact melt produced by the event and subsequent potential differentiation of the melt volume. Clasts in breccia and geochemical mixing analysis using clast compositions will reveal target lithologies, including deep crustal and mantle components. The compositional "anomaly" that still exists in the interior of SPA reflects a mafic (Ferich) composition [19]. However, until we have direct samples of the materials that give rise to the compositions, we will not know fully how to interpret them. The same holds for the mineralogical signatures seen in orbital spectroscopic data [e.g., 20,21]. Recent mapping of mafic mineral signatures in crater central peaks and elsewhere [22] reflects a mixture of SPA substrate lithologies produced by differentiation of the melt sheet [23-25] and later volcanic rocks. Samples are essential to ground-truth the orbital data.

Thermal Evolution of the Moon. Samples will be used to investigate sources and distribution of Th and other heat-producing elements to understand lunar differentiation and thermal evolution. Orbital measurements show a modest Th anomaly associated with the SPA interior, and it is possible that SPA is old enough to have occurred prior to the final migration and solidification of KREEP-rich materials. Coupling this signature with identification of host lithologies and age will enable new tests of models of lunar differentiation and the origin of the Moon's prominent asymmetries, and of whether the orbital SPA Th signature is associated with differentiation of the SPA impact melt body [24].

Volcanic Components. SPA did not apparently undergo basaltic filling and resurfacing to the same extent as nearside basins such as Imbrium. Nonetheless, volcanic rocks occur in the interior of the basin both as exposed mare basalts and buried "cryptomare" [26,27]. Analysis of Apollo regolith samples indicates that lateral transport will have introduced fragments of these rock types to regolith everywhere in SPA. Ages and compositions of SPA basalts will allow us to determine how mantle source regions (composition, volatiles, mineralogy, thermal history, depth of melting, model ages) on the Moon's far side compare to basalts sampled by Apollo, Luna, and lunar meteorites. A sample location near the center of SPA should include fragments of rock from the "Mafic Mound," which may be an ancient volcanic construct associated with the formation of SPA and the evolution of its melt sheet [28]. Isotopic, geochemical, and mineralogical analysis of these volcanic materials will help determine global mantle heterogeneity, the nature, timing, and extent of primordial lunar differentiation, and post-differentiation magmatic/thermal evolution of the mantle (e.g., overturn of magma ocean cumulates).

Volatile-element contents. New discoveries have emphasized the importance of volatiles – both exogenous and endogenous – in the Moon's history. Lower crustal materials in SPA samples will offer the opportunity to investigate endogenous volatiles in a variety of new and different kinds of lithologies relative to Apollo and Luna samples. Agglutinates in central or southern SPA should contain a record of more southerly surface volatiles, and potentially exogenous volatile-bearing deposits. Stable isotope compositions of small samples record processes as well as origin. Modern analytical methods (SIMS and individual grains) minimize sample mass needed and improve detection limits [29]. Coupled with chronology, results provide time-stamped volatile information in both magmatic and surface samples.

MoonRise Approach: The MoonRise mission concept will sample rock materials in the regolith by scooping and sieving to extract at least 900 g or more of rock fragments 3-20 mm, amounting to many thousands of small rock fragments. Over 100 g of bulk regolith will also be collected. This approach leverages the impact process, which delivers a variety of local rock materials to any given site. The efficiency of this process is well documented in the Apollo samples, which also document variations in rock fragment abundance with depth and dictate that samples must be collected from beneath the upper few cm. The complexity of the integrated chronologic, geochemical, paleomagnetic, and petrographic analyses needed to achieve science objectives *requires* that samples be returned from the Moon; in-situ analysis is not an option. Samples returned to Earth would be curated at Johnson Space Center and 75% of the sample mass would be available for allocation to the worldwide scientific community.

References: [1] Gomes et al. (2005) *Nature* **435**, 466-469. [2] Marchi et al. (2012) *EPSL* ***325-326***, 27-38. [3] NRC (2011) *Vision and Voyages for Planetary Science in the Decade 2013-2022*, *Natl. Acad. Press*. [4] Tera et al. (1974) *EPSL*. **22**, 1-21. [5] Garrick-Bethel & Zuber (2009) *Icarus* **204**, 399-408 [6] Schultz & Crawford (2015) *LPSC* **46**, #2416. [7] Kring et al. (2015) *Early SS Impact Bombardment III*, #3009. [8] Borg et al. (2015) *MAPS* **50**, 715-732 [9] Shearer et al. (2015) *Am. Min.* **100**, 294-325 [10] Kendall et al. (2015) *LPSC* **46**, #2765. [11] Hiesinger et al. (2012) *LPSC* **43**, #2863. [12] Van der Bogert et al. (2017 LPSC 48, #1437. [13] Turner (1977) *Phys. Chem. Earth* **10**, 145-195. [14] Papanastassiou and Wasserburg (1971) *EPSL* **12**, 36-48. [15] Norman et al. (2016) *GCA* **172**, 410-429. [16] Grange et al. (2013) *GCA* **101**, 112-132. [17] Merle et al. (2014) *MAPS* **49**, 2241-2251. [18] Potter et al. (2012) *Icarus* **220**, 730-743. [19] Lawrence et al. (2007) *GRL* **34**. [20] Lucey et al. (1998) *JGR-P* **103**, 3701-3708 [21] Pieters et al. (2001) *JGR-P* **106**, 28,001-28,022. [22] Moriarty et al. (2013) *JGR-P* **118**, 2310-2322. [23] Vaughan & Head (2013) *Planet. Space Sci.* **91**, 101-106. [24] Hurwitz and Kring (2014) *JGR-P* **119**, 1110-1133. [25] Cassanelli & Head (2016) *GRL* **43**, 11,156-11,165. [26] Yingst & Head (1999) *JGR-P* **104**, 18,957-18,979. [27] Whitten & Head (2015) *Icarus* **247**, 150-171. [28] Moriarty & Pieters (2015) *GRL* **42**. [29] Hashizume & Chaussidon (2009) *GCA* **73**, 3038-3054.